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WORKSHOP ON "RECENT PROGRESS IN SURFACE AND VOLUME SCATTERING"

Instituto de Optica, C.S.I.C. Madrid. Spain.

14 – 16 September 1988

DAJA45-88-M-0137

Sponsored by:

European Research Office of the US Army,
C.S.I.C. and Sociedad Española de Optica.

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Sponsored by **European Research Office of the US Army** and **Sociedad Española de Optica.**

Organizer:

M. Nieto–Vesperinas, Instituto de Optica, C.S.I.C., Spain.

Programme committee:

J. C. Dainty, Imperial College, London, U.K.

R. Petit, Université d'Aix Marseille, France.

Topics to be covered:

Surface scattering

Limitations of Physical Optics.

Surface plasmon effects.

Enhanced backscattering.

Numerical solutions.

Polarization effects.

Inverse problems.

Periodic structures.

Volume scattering

Enhancement and photon localization.

Polarization and anysotropy effects.

Dynamic scattering by dense media.

Double pass effects through phase screens.

WORKSHOP ON "RECENT PROGRESS IN SURFACE AND VOLUME SCATTERING"

Instituto de Optica, C.S.I.C.

Madrid, Spain. 14 – 16 September 1988

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WORKSHOP ON "RECENT PROGRESS IN SURFACE AND VOLUME SCATTERING"

Program

14 – 16 September

Wednesday 14

9:30 – 11:00

A. Ishimaru:
Experimental and theoretical studies on enhanced backscattering from scatterers and rough surfaces.

E.R. Méndez and K. O'Donnell:
Scattering experiments with smoothly varying random rough surfaces, and their interpretation.

11:00 – 11:30 Coffee break

11:30 – 1:00

J.C. Dainty, M.J. Kim and A.J. Sant:
Measurements of enhanced backscattering of scattered light from one and two dimensional random rough surfaces.

M. Nieto-Vesperinas and J.M. Soto-Crespo:
Electromagnetic scattering from very rough random surfaces and deep reflection gratings.

3:00 – 4:30

A. Maradudin, E.R. Méndez and T. Michel:
Scattering of light from rough surfaces

D. Maystre:

Rigorous solution of problems of scattering by large size rough surfaces.

4:30 – 5:00 Coffee break

5:00 – 6:30

Gary S. Brown:

The method of smoothing applied to random surface and volume scattering.

N. García:

Exact calculations of scattering of waves by slits.

Thursday 15

9:30 – 11:00

R. Petit and M. Cadilhac:

Functional analysis and diffraction theory (2 talks together)

11:00 – 11:30 Coffee break.

11:30 – 1:00

R. Schiffer:

Scattering of EM waves from particles with random rough surfaces.

E.L. Church:

Specular reflection of optical and X–ray radiation from rough surfaces.

3:00 – 4:30

R.A. Depine:

Surface impedance boundary conditions used to study light scattering from metallic surfaces.

A. Consortini:

Role of the inner scale of atmospheric turbulence in optical propagation and methods to measure it.

4:30 – 5:00	Coffee break
5:00 – 6:30	
	J. Stamnes and L.J. Gelius:
	Diffraction tomography imaging. Potentials and problems.
	M. Cessenat:
	The use of Calderon projectors and capacity operators in scattering.
6:30	Wine & Sherry

Friday 16

9:30 – 11:00	
	A. Lagendijk:
	Latest developments in weak localization of light.
	I. Freund:
	Weak localization of light, coherent backscattering in 2–D systems and dynamic multiple scattering.
11:00 – 11:30	Coffee break
11:30 – 1:00	
	E. Jakeman:
	The physical optics of enhanced backscattering.
	P. Bruscaglioni and G. Zaccanti:
	Multiple scattering in dense media.

3:00 – 5:00

R. Reinisch, M. Neviere, J.L. Coutaz and D. Maystre:

Surface plasmon enhanced second harmonic generation at metallic gratings.

G. Stegeman:

Third order non–linear interactions at surfaces and in thin films.

J.E. Sipe:

Intrinsic inestabilities of laser–irradiated surfaces.

EXPERIMENTAL AND THEORETICAL STUDIES ON ENHANCED BACKSCATTERING FROM SCATTERERS AND ROUGH SURFACES

Akira Ishimaru
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University of Washington
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ABSTRACT

This paper presents recent experimental and theoretical investigations of backscattering enhancement. We reported in 1984 on an optical experiment with latex spheres which showed a strong enhancement of the backscattering with a narrow peak. Subsequently, we reported on a theory based on cyclical or crossed terms using the diffusion theory that the enhancement is caused by the constructive interference of two waves traversing through the same particles in opposite directions. This phenomena cannot be explained by the classical radiative transfer theory. We have continued experiments for particles with various sizes and examined the relationship between the enhancement and particle sizes and densities. We also examined the enhancement of backscattering from rough surfaces in terms of the extension of the diagram method and compared it with recent experimental and numerical data.

SCATTERING EXPERIMENTS WITH SMOOTHLY VARYING RANDOM ROUGH SURFACES, AND THEIR INTERPRETATION.*

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and
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GEORGIA, USA.

Light scattering experiments with specially prepared random rough surfaces have been performed. The height variations on these surfaces approximate a Gaussian Random Process with a Gaussian autocorrelation function. They provide examples of smoothly varying random surfaces characterized by a single scale.

Surfaces with various roughness scale parameters and correlation lengths were prepared. Perhaps the most interesting ones are those that possess large r.m.s. slopes, since they exhibit quite unusual scattering behaviour. They produce large amounts of depolarization, and backscattering enhancement.

Based on our observations, we have interpreted these results with the aid of a double scattering model that at least qualitatively agrees with the measurements. There have however been some recent attempts to fit the experimental data with the predictions of single scattering models. We do not question the fact that a single scattering model can predict backscattering enhancement and depolarization but we have evidence that a significant amount of double scattering is taking place on our surfaces. Thus, we believe that the fact that a single scattering theory is able to fit the experimental data reasonably well is only a coincidence, and that it does not necessary imply that single scattering is responsible for the phenomena observed. These issues will be discussed in this talk.

*The experimental work was carried out when the authors were with the Applied Optics Section, Imperial College, London.

MEASUREMENTS OF ENHANCED BACKSCATTERING OF SCATTERED LIGHT FROM ONE- AND TWO-DIMENSIONAL RANDOM ROUGH SURFACES.

J C Dainty, M-J Kim, A J Sant
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Imperial College
London SW7 2BZ, UK

Summary

Enhanced backscatter peaks in the diffuse envelope of scattered light from single scale, isotropic, two-dimensional randomly rough metallic surfaces were first reported by O'Donnell and Mendez[1]. The surfaces, however, were of large slope, thus making the experimental data unsuitable for comparison with the available theoretical and numerical analysis of light scattering. In an attempt to provide a bridge between experimental data and theoretical analysis, a number of new experiments were carried out. These include:

- measurements of the scattered light from a series of two-dimensional surfaces with similar $1/e$ correlation length and different rms surface height fluctuation
- measurements of Stokes' parameters of the scattered light from two-dimensional surfaces exhibiting the enhanced backscatter peak
- measurements of scattered light from approximately on-dimensional randomly rough surfaces (i.e. random gratings) for *s*- and *p*- polarisations of the incident light

A new method of characterising the rough surfaces using a confocal scanning microscope is also being studied and it is hoped to report on its effectiveness compared to stylus measurements.

1 K A O'Donnell and E R Mendez, J. Opt. Soc. Am. A4, 1194-1205 (1987)

ELECTROMAGNETIC SCATTERING FROM VERY ROUGH RANDOM SURFACES AND DEEP REFLECTION GRATINGS

M. Nieto–Vesperinas and J.M. Soto–Crespo
Instituto de Optica, CSIC,
Serrano 121
28006 Madrid. Spain

Summary

A study of perfectly conductive very rough *one–dimensional random surfaces* and deep reflection gratings is presented by means of the extinction theorem.
Concerning random surfaces the main results to be discussed are:

1) Differences between the distributions of mean scattered intensity for s and p–polarization for both σ/λ and T/λ small, but σ comparable to T; σ being the r.m.s. of random heights and T their correlation length.

2) Prediction of enhanced backscattering and analysis of its variation with the angle of incidence.

3) Prediction of quasi–Lambertian behaviour for σ moderately large, but σ/T smaller than values at which enhanced backscattering is observed.

4) Discussion on the range of validity of the Kirchhoff approximation when $T < \lambda$.

As for deep reflection gratings we shall discuss:

1) Blaze of the antispecular intensities, even at large incidence angles.

2) Existence of gratings with blaze in all antispecular orders.

3) High probability of blaze of the antispecular intensity for a profile given *a priori*, and high probability of blaze in the specular when the profile is symmetric.

4) Connection of blaze in the antispecular and backscattering enhancement from random surfaces.

5) Enhancement in both the specular and antispecular directions for the mean scattered intensity from deep random surfaces in which a center of symmetry has been introduced.

Scattering of Light From Rough Surfaces*

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By the use of Green's second integral theorem we have written an exact expression for the scattered electromagnetic field produced by a p-polarized beam of finite width incident from the vacuum side onto a random metallic grating whose grooves are perpendicular to the plane of incidence. The scattered field is expressed in terms of the values of the total magnetic field and its normal derivative on the surface of the grating. The coupled pair of integral equations satisfied by these functions is solved numerically for each of several hundred (~ 900) realizations of the surface profile, which are generated numerically and possess a Gaussian spectrum. The resulting differential reflection coefficient averaged over these realizations of the surface profile displays a well-defined peak in the retroreflection direction in both the small roughness and strong roughness limits. These theoretical results are compared with experimental data and with theoretical results obtained for perfectly conducting random gratings and for random gratings on dielectric surfaces. Results are also presented for the scattering of a p-polarized beam of finite width from a groove or step on an otherwise planar metal surface, and the efficiency of exciting surface polaritons in this manner is obtained.

*Research supported in part by Army Research Office Grant No. DAAG29-85R-0025.
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RIGOROUS SOLUTION OF PROBLEMS OF SCATTERING BY LARGE SIZE ROUGH SURFACES

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FACULTE DES SCIENCES & TECHNIQUES DE ST.JEROME - 13397 MARSEILLE CEDEX 13 (FRANCE)

The aim of the communication is to present two methods able to overcome the difficult problem of the rigorous calculation of the field scattered by a rough surface the width of which is very large compared to the wavelength.

The first one is called "beam simulation method" and has been applied to 2D, perfectly conducting, metallic or dielectric random rough surfaces. Using for instance a point matching method, the rigorous integral theory of scattering is able to provide the diffraction pattern of a random rough surface illuminated by a light beam, provided that the width of the beam does not exceed about 10 wavelengths. For larger beams, this formalism leads to the inversion of very large size matrices, which cannot be performed accurately. The basic principle of the "beam simulation method" is to show that a large beam can be represented as the sum of very narrow beams. Since each of these narrow beams illuminates a small part of the rough surfaces, the elementary problem of scattering from one of these beams can be easily solved. The diffraction pattern generated by the large beam is the sum of all the elementary scattering patterns from the narrow beam. Numerical examples will be given, in particular for perfectly conducting or metallic random rough surfaces.

The second method has been applied to "echelle" gratings, viz. gratings having a groove spacing very large compared to the wavelength. By modifying the integral equation, it can be shown that the problem of scattering can be rigorously solved without high memory storage or inversion of very large matrices, whatever the groove spacing over wavelength ratio.

The only shortcoming of these two methods is the computation time, which increases linearly with the size of the rough surface.

THE METHOD OF SMOOTHING APPLIED TO RANDOM SURFACE AND VOLUME SCATTERING

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A distinct trend in the analysis of problems dealing with random wave propagation and scattering is the use of computers to obtain solutions in regions where asymptotic and approximate results are not valid. With a few notable exceptions, computers have been used primarily in implementing Monte Carlo type simulations. In such an approach, the quantity of interest is computed via numerical means for a large number of different realizations of the random enviornment and the results from all of these realizations are averaged to generate an ensemble average. While this is a reasonably straightforward approach, it has some drawbacks. Therefore, there are some very good reasons to examine other numerical approaches; one such candidate is iteration. That is, if the problem can be formulated as an integral equation of the second kind, it can be solved at least formally by iteration. Iteration is not usually considered a numerical method, but, on the other hand, very little can be done from a practical standpoint without some clever methods to evaluate the integrals contained in the iterates.

With random wave propagation problems, the integral equation can first be "solved" via iteration and then the statistical operations are applied to this formal result to generate the desired statistical moment. There are cases, however, where the convergence of the resulting solution is either non-existent or is asymptotic and the standard iterative approach is therefore limited.

Fortunately, there is an alternative to the standard iterative approach and this is the method of smoothing (MoS). *In the MoS, the basic integral equation of the second kind is manipulated into coupled integral equations for the mean or average of the scattered or propagating field and the zero-mean fluctuating part of of the same field quantity.* The fluctuating field equation is solved by means of iteration *assuming that the mean field is known.* This result is substituted in the mean field equation to produce an iterative-like solution for the mean field. Assuming that this equation can be solved, the integral equation for the fluctuating part involves the mean field in its Born or source term. *The MoS provides an alternate iterative solution which may converge when the standard iterative approach fails to do so.*

This paper will concentrate on the *fluctuating field* part of the MoS solution when applied to random surface and discrete volume scattering. This concentration on the fluctuating field is a result of a need for the incoherent power (which is determined entirely by the fluctuating field) and the fact that most previous work has been concerned with the mean or average field.

It will be shown that, in the case of surface scattering, the MoS degenerates to the standard iterative approach when the surface roughness is large compared to a wavelength. When the surface roughness is small compared to a wavelength, the MoS solution for the fluctuating scattered field clearly shows a dependence on the horizontal surface structure even in the Born term. With discrete random media, the Born term in the integral equation for the fluctuating part of the scattered field appears to be the same as deWolf's "cumulative forward single backscatter" approximation. This term does not agree with distorted wave Born approximation in which the average medium Green's function is used instead of the free space form. An interesting aspect of the fluctuating field integral equation is the obvious need for some form of partial summation in the limit of very small mean or average field.

EXACT CALCULATIONS OF SCATTERING OF WAVES BY A SLIT.

N.García

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In this work we present exact calculations for the scattering of scalar waves by slits or holes in a screen.

The slits are of a general shape and the screen is defined by a dielectric medium of dielectric constant $\varepsilon(\omega) = \varepsilon_1 + i\varepsilon_2$ and by a given thickness l. The transmission of the wave as well as its diffraction is largely influenced by the screen's thickness. The Kirchoff approximation fails completely for certain incident angles and values of l. This will be discussed in the talk. Also it will be shown that the solution to the problem of scattering of waves by metallic screens with holes is equivalent to the solution of tunneling of plane waves for scanning tunneling microscopy in the contact regime when the tunnel barrier is defined by an optical potencial. Therefore the diffraction of light waves can be used to understand and create emission of coherent electron beams from very small sources. These beams could be used to perform electron holography with 3-D atomic resolution.

FUNCTIONAL ANALYSIS AND DIFFRACTION THEORY

by R.Petit and M.Cadilhac

LABORATOIRE d'OPTIQUE ELECTROMAGNETIQUE
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13397 MARSEILLE CEDEX 13

N.B. In what follows we summarize some theoretical works recently carried out in our group in collaboration with G.Bouchitté and G.Tayeb.

1.HOMOGENIZATION TECHNIQUES AND PERIODIC STRUCTURES.

When studying the diffraction by a grating it is possible to replace the groove region by an inhomogeneous transition layer(called the homogenized structure)whose optical parameters (optical index, permittivity...) are obtained by a certain averaging process. Some years ago, we discussed this question from rigorous arguments of functional analysis. Let us consider a family G_n of conducting gratings with a fixed depth, but a variable period $d = d_0/n$. When a grating G_n is illuminated by a given incident field, it gives raise to a total field $u_n(x,y)$. It turns out that the limit $\tilde{u}(x,y)$ of $u_n(x,y)$ when n tends to infinity,as well as the homogenized structure, are depending on the polarization. We will give the results (already published) and also comments on the types of convergence we have to use.

2.DIFFRACTION BY INFINITELY THIN AND INFINITELY CONDUCTING SCREENS.(to be published in Radio Science,1988, June issue)

Let us consider a conducting rod $T_n(\epsilon_0,\mu_0,\sigma_n)$ with a cross-section represented on Fig.1. Let $u_n(x,y)$ be the total field when the rod T_n is illuminated by a fixed incident field . We look for the limit $\tilde{u}(x,y)$ when simultaneously the thickness $h_n = h_0/n$ and the resistivity $\rho_n=1/\sigma_n$ tend to zero. The result has been obtained as a part of a thesis of Mathematics by G. Bouchitté. It is worth noting that $\tilde{u}$ depends on the polarization,on the

shape of the initial cross-section (i.e. the function f) and on how the two vanishing parameters are linked. In general the Joule effect does not go to zero, in contradiction with what is usually assumed in the literature.

3. THE GENERAL GRATING PROBLEM REVISITED IN ORDER TO INCLUDE THE CASE OF ANISOTROPIC MEDIA. (in collaboration with G. Tayeb)

When dealing with the electromagnetic theory of gratings ruled on isotropic substrates, we have to face cumbersome and tedious calculations. For this reason, we have been compelled to undertake a structural analysis of the general diffraction problem(isotropic or anisotropic media) in the case of periodic obstacles . We dwell on the construction of characteristic idempotent or involution operators on a convenient functional space. When these operators are known, as well as their eigenspaces, the grating problem can be presented in a "geometrical" form : To find the intersection of two linear manifolds.

To illustrate this point,we have solved the diffraction of a plane wawe by a grating y=f(x) filled with an anisotropic matérial of a particular type (the permittivity matrix being diagonal in the Oxyz frame).The relevant Green fonctions have been given explicitly and a reliable computer program has been achieved.

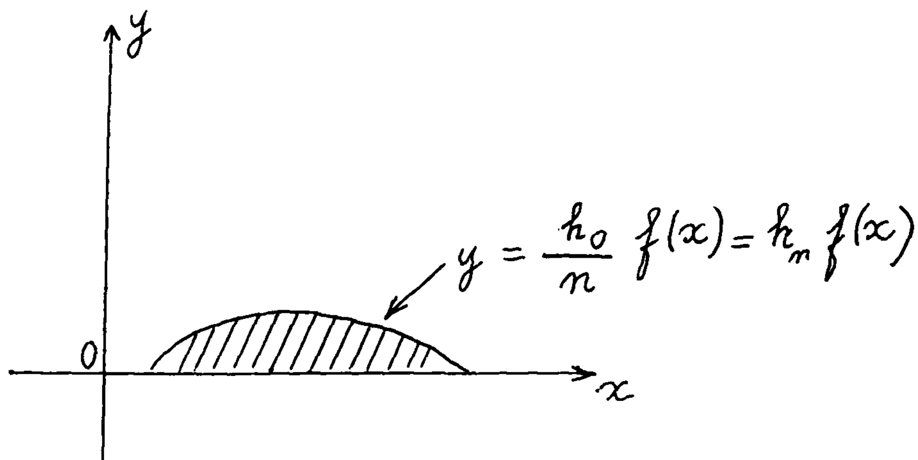

Figure 1. The conducting material corresponds to the hatched region

SCATTERING OF ELECTROMAGNETIC WAVES FROM PARTICLES WITH RANDOM ROUGH SURFACES

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Abstract:

In most applications of light scattering by particles one is faced with scattering or absorption measurements not of a single, arbitrarily irregular particle, but of a cloud of many particles, e.g. with random orientation. Here the question arises which properties of the particles can be inferred from these measurements in spite of the information loss caused by the averaging over the particle ensemble (inverse scattering problem). A first step towards the solution of this problem is to calculate the average scattering properties of a randomly oriented cloud of particles characterized by certain parameters that determine their size and shape distribution (direct scattering problem). However, calculating the scattering cross section of a single irregular particle and taking the average afterwards is a very difficult task; therefore, in this paper a statistical approach is presented: instead of a particle ensemble, a single dielectric particle with stochastic surface properties is considered. This method combines the perturbation approach for particle scattering by Yeh and Erma with the well-known Rayleigh-Rice method for light scattering from statistically rough planar areas. Because of the perturbative treatment this method is appropriate only for moderate deviations of the particles from the spherical shape. It turns out that within the range of validity of this approach the surface auto-correlation function and the size parameter uniquely determine the average scattering behaviour of the particles. The scattering cross sections result as expansions in generalized spherical functions, which are of importance in the theory of radiative transfer of polarized light. Limiting cases of large and small wavelengths are discussed and are shown to agree with results found in the literature.

ESPECULAR REFLECTION OF OPTICAL AND X-RAY RADIATION FROM ROUGH SURFACES

E. L. Church

Department of the Army

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Dover, NJ 07801, USA

Abstract not available

SURFACE IMPEDANCE BOUNDARY CONDITIONS USED TO STUDY LIGHT SCATTERING FROM METALLIC ROUGH SURFACES

Ricardo A. Depine, Universidad de Buenos Aires

The scattering of a plane wave by a closed surface S can be excatly solved by making use of the boundary conditions that state the continuity of the tangential components of the electric and magnetic fields. On the other side, if the ratio between those components along the surface (surface impedance Z) is known the problem can also be solved: Z may then be used as a boundary condition that enables us to find the fields outside S without solving the wave equation inside the surface S. Unfortunately, Z depends not only on the shape and nature of the scatterer but also on the incident field, and so its determination generally involves the whole solution of the problem.

The idea of postulating "a priory" the dependence of Z on the parameters of the problem and using it as a boundary condition to solve the scattering problem has seemed attractive to many authors. In the context of the electromagnetic theory of gratings the approximation $Z=1/n$ (n being the complex index of refraction of the metal), in conjunction with techniques associated with the perfectly conducting model, was used as the basis of a method for calculating grating efficiencies which provided reliable results for highly conducting metals and surfaces with low local curvature. The validity of the boundary condition, however, remained to be tested, since Z has never been calculated rigorously.

In this communication we will present exact calculations of the surface impedance for several gratings. The dependence of Z on the angle of incidence and on the position along the surface will be shown. We will also present the efficiency curves obtained from a method based on the mentioned aproximation and compare them to the ones obtained by rigorous methods. Problems that arise as the local curvature is increased and for grazing incidences will be discussed and a possible improvement of the expression will be analyzed.

ROLE OF THE INNER SCALE OF ATMOSPHERIC TURBULENCE IN OPTICAL PROPAGATION AND METHODS TO MEASURE IT

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The effect of the small inhomogeneities of the atmospheric turbulence on differential angle-of-arrival fluctuations of large beams and on wandering of thin beams is analized. The possibility of obtaining the value of the inner scale through measurements of the above quantities is discussed. A property of the correlation functions that strongly depends on the inner scale for both angle-of-arrival and wandering is examined. A method for measuring the inner scale based on this property is described and same experimental results are presented. The property appears not to depend on the particular model of turbulence used to derive it, and therefore the method seems to be quite general.

DIFFRACTION TOMOGRAPHY IMAGING - POTENTIALS AND PROBLEMS

Jakob J. Stamnes and Leiv-J. Gelius
Norwave Development A.S, Oslo, Norway

ABSTRACT

In recent years many different algorithms have been developed for reconstructing objects from scattering data. But it still remains in many cases to determine under what circumstances a given algorithm provides reliable reconstructions.

In previous studies of penetrable objects scattered data have usually been obtained from approximate solutions based on the Born or Rytov assumption. But since they usually give scattered data based on the same assumptions as used in the inverse modelling, they can only serve to cheque the implementation of the reconstruction algorithm. In a quantitative study it is important to have reliable scattered data for objects of variable contrast and shape. For this reason we have developed exact solutions for acoustic scattering by a penetrable elliptic cylinder.

We consider the filtered back propagation algorithm of Devaney which is based on the Rytov approximation. To examine its validity we first generate exact scattered data and then run these through the inversion algorithm to see how close the reconstruction comes to the original object. In this manner we determine how the accuracy of the algorithm depends on the wavelength of the incident wave and the number of views employed, as well as on the size, geometry and contrast of the object.

Applications in medical diagnostics, geophysics, and geotechnics will be discussed along with some of the problems which then arise.

The use of the Calderon Projectors and the Capacity Operators in Scattering.

M. Cessenat, CEA, CEL. FRANCE.

Abstract.

The usual physicist concepts of surface impedance and of capacity are taken into account and generalized by the Calderon projectors and the capacity operators in the case of scalar waves which satisfy the Helmholtz equation and in the case of electromagnetic waves which satisfy the stationary Maxwell equations. Two essentially different situations are considered:

- case of a bounded domain in $\mathbb{R}^3$ (inside case, then outside case with radiating Sommerfeld conditions, or Silver-Müller conditions at infinity).
- case of a plane geometry, for outgoing or incoming waves.

The trace spaces, which are the usual mathematical framework of these integral singular Calderon operators are given.

Many uses may be put forward: for instance the outside Calderon projector allows to transform any scattering problem with an inhomogeneous bounded obstacle Ω into a differential problem in Ω with an integral boundary condition. The use of the Calderon projectors and the capacity operators is a very powerful means to solve numerous problems (diffraction, interference, scattering,..) in very different situations.

Abstract for workshop "Recent progress in surface and volume scattering" to be held in Madrid 14-16 september 1988 in the "Instituto de Optica".

Recent developments in localization of waves*

by

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In our group both experimental and theoretical work on the localization of waves is performed. In this abstract ongoing research will be discussed.

The experimental emphasis is on the study of propagation of femto-second optical pulses in disordered materials. We have been able to study the weak localization of light (enhanced backscattering) with a time-resolution of twenty femto-seconds. In addition we have studied the depolarization of the scattering as a function of time. For the interpretation of the latter our previously performed numerical simulation of multiple Rayleigh scattering turned out to be very useful. Numerical simulations on diffusive transport were extended to study the influence of boundary conditions.

An important issue in the interpretation of the weak-localization experiment is the magnitude of the enhancement factor. We will show that there is no fundamental reason why this factor should be exactly two. This holds both for scalar scattering as well as for Rayleigh scattering. We will comment on our experimental results for the enhancement factor.

There is a great similarity between optical speckles and universal conduction fluctuations for electrons. Although speckles have been known for a long time in optics, the approach of the condensed matter theoreticians is quite original and may have important consequences for optical speckles as well. We will report on our experiments.

We have developed a numerical method, based on path-integral techniques, to study propagation of waves described by a parabolic wave equation. Results for a new form of localization:"transverse localization" will be presented. Propagation on fractal networks is studied as well.

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* work in collaboration with M.P. van Albada, M.B. van der Mark, H. De Raedt, R. Sprik, R. Vreeker, and P. de Vries.

Weak Localization of Light and Enhanced Coherent Backscattering in Two Dimensional Systems

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Weak and strong localization of light and enhanced coherent backscattering are areas of intense current interest. The dimensionality of the system plays a major role in these phenomena, so that in 3D, strong localization requires a mean free path shorter than the wavelength of light, while in 2D and in 1D, a finite localization length is obtained for any value of the mean free path. Accordingly, studies of low-dimensional systems are being actively pursued by many groups. We have very recently completed what appear to be the first experiments on coherent backscattering of light in a two dimensional system.[1] Although the classical approach to achieving a 2D sample in electron transport, for example, is to use thin films (e.g. inversion layers), in optics the equivalent system is extremely difficult to realize experimentally. The essential problem is the fabrication of the broadband, lossless mirrors needed to confine the photon within the sample plane. Recognizing that it is the multiply-scattered photon trajectory which must be planar, rather than the physical dimensions of the sample, we have successfully constructed an optically 2D system using long, parallel, randomly spaced rods whose diameters are somewhat smaller than the wavelength of light, and whose lengths exceed 1 mm. Because the momentum transfer parallel to the rod axes approaches zero, a photon injected perpendicular to the rods executes a planar random walk, thereby exhibiting 2D behavior. Relevant aspects of the theory of weak localization of photons in 2D systems will be reviewed, the use of an anisotropic diffusion equation to model low dimensional systems of finite extent will be described, and a continuous characterization of dimensionality suitable for analysis of real systems will be discussed. Our theoretical expressions[1] for the coherent backscattering in finite 2D samples, which include the effects of small deviations from perfect 2D will be presented, and the crossover behavior of the backscattered peak as the system dimensionality is continuously varied between 2D and 3D will be described. Our recent experiments[1] on the 2D coherent backscattering will be presented, and compared with the theoretical predictions. Generally, a reasonable level of agreement between theory and experiment is found. By studying the wide-angle diffuse scattering, we have also obtained what appear to be the first experimental data[1] on the steady-state distribution of photons inside a random two-dimensional medium. These data will be compared with theoretical predictions obtained from solutions of both the two-dimensional photon diffusion equation and the two-dimensional Milne equation. For the transmitted light, the relative photon density just inside the boundary is found to be approximately 20% greater than the 2D Milne equation prediction of 0.8. For the reflected light, a very flat photon density distribution near the boundary is found, in qualitative, but not quantitative, agreement with photon diffusion theory in which a continuous injection of photons by the incident beam is included. Prospects for observing the predicted weak localization 2D logarithmic correction to the optical transmission will be discussed, and possible 2D experiments of special interest will be suggested.

[1] I. Freund, M. Rosenbluh, R. Berkovits, and M. Kaveh (to be published).

Recent Progress in Dynamic Multiple Scattering

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During the past year there have been substantial advances in our understanding of multiple scattering of light by dynamic systems.[1-7] Dense, albeit substantially noninteracting systems undergoing random Brownian motion provide a suitable testing ground for recent theoretical developments. A review of these theories, including a searching examination of the underlying assumptions will be presented. One of the most dramatic predictions of the theory[1] is that for backscattering, the dynamic intensity-intensity correlation function C(t) is a universal function of t/τ_1, where τ_1 is the angle-averaged single scattering correlation time. For diffusive scatterer motion, C(t) is found to decay to half its initial value in about $1/25^{th}$ of τ_1, resulting in a rapid, 25-fold acceleration in the time evolution of multiply-scattered speckle patterns. This factor of 25 $[=12/(\ln 2)^2]$ thus provides a simple, convenient, universal characterization of dynamic backscattering for diffusive systems. High-speed video images[1,2] of the time evolution of multiply scattered light from randomly diffusing polystyrene spheres which dramatically illustrate the theoretical predictions will be presented. C(t) is obtained by digitizing these images, and excellent agreement is found with theory. Recent results by other groups,[4,5] which are also in full accord with the theory, will be reviewed. Another important prediction of the theory,[1] also verified by experiment, is that in the long time limit C(t) reverts to the form for single scattering. This long time limit is reached for t of order τ_1, and appears to be easily accessible with good signal/noise.[4] Accordingly, particle dynamics in dense, interacting, strongly multiply scattering systems may be studied using well established methods of interpretation. The rate at which a dense, dynamic system approaches its ensemble average is also currently of special interest. This may be monitored via the degradation in optical contrast of multiply scattered speckle patterns as ensemble averaging proceeds.[1] High speed video images[1] illustrating this behavior will be presented and compared with theory In transmission, as opposed to backscattering, C(t) is nonuniversal, and depends sensitively both on the system parameters and on the system geometry. The reasons for this will be discussed, and the theoretical predictions for a wide range of geometries[5-7] will be reviewed. For long correlated optical paths, the photon diffusion approximation, which is central to current theories, and which neglects correlations, begins to break down. Recent experiments[3] supporting this prediction will be reviewed, modifications of the theory will be suggested, and a predicted crossover behavior[3] will be discussed. The currently most pressing problems in this rapidly developing area will be reviewed.

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THE PHYSICAL OPTICS OF ENHANCED BACK-SCATTERING

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Several observations of enhanced back-scattering of coherent light from volume scatterers such as particle suspensions have been reported over the last few years. These can be explained by the coherent addition of doubly scattered waves which add in phase only in the backward direction. However, strong enhancement has also been observed recently in light scattered by smoothly varying random surfaces with inhomogeneities whose dimensions are significantly larger than the incident wavelength(1). The exact solution of Maxwell's Equations for such systems is notoriously difficult. We have therefore undertaken a theoretical and experimental investigation of a simpler but generic system which can exhibit all the double scattering effects contained within small angle scalar diffraction theory. This should establish a phenomenological basis for the interpretation of enhanced back-scattering in systems governed by Physical Optics, although some embelishment will be necessary to explain polarisation effects.

The model consists of a random phase changing screen in front of a reflecting surface. As well as elucidating enhanced back-scattering from rough surfaces, the predictions of this model are relevant to many propagation problems where waves are back reflected through extended media containing refractive index fluctuations(2). They are also relevant to multipath problems encounted in radar and sonar systems.

An initial theoretical investigation of the statistical properties of this model indicates that enhancement in the backward direction may occur due to coherent addition of doubly scattered waves, as in particle scattering systems, and also as a result of statistical geometrical optics effects. Experimental results confirm these theoretical predictions.

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MULTIPLE SCATTERING IN DENSE MEDIA

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After a brief recalling of the calculation scheme used to evaluate the transmittance of a light beam through a turbid medium (Semi Monte Carlo code including the use of scaling formulas), an exposition will be made of the last results obtained in our laboratory concerning the effects of different geometrical situations (thin, or conical or cylindrical beam , relative positions of scattering medium, source and receiver). With regard to the effect of multiple scattering on the time elongation of short light pulses, first examples with be shown of evidence of this effect, obtained by an indirect method based on the use of a continuous laser beam. The separation between received scattered and unscattered power allows us to evaluate the different attenuation of the two quantities due to the different path lengths within an absorbing medium (suspension of non absorbing polystyrene spheres in water to which different amounts of absorbing dye are added.

SURFACE PLASMON ENHANCED SECOND HARMONIC GENERATION AT METALLIC GRATINGS

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This paper is concerned with surface enhanced (SE) second harmonic generation (SHG) through delocalized surface plasmon (SP) resonance excited by a metallic grating (periodicity d, groove depth δ). Due to the existence of the grating, a phenomenon of diffraction in nonlinear optics (NLO) occurs, i.e. diffraction at the SH frequency.

The theory we have developed fully includes :

* The specific features concerning the NL polarization in metals [1]. Namely the existence of a surface NL polarization, $\vec{P}_s^{NL}$, (which has both tangential and perpendicular components) and the corresponding boundary conditions at 2ω. We show that $\vec{P}_s^{NL}$ is located on the metal surface (and not above it). We also demonstrate that the component of $\vec{P}_s^{NL}$ perpendicular to the interface leads to a jump of the tangential component of the electric field at 2ω. The expression of this jump has been derived in term of the pump field.

* The diffraction process, not only at the pump frequency ω, but also at the new frequency 2ω. This allows dealing with the SP resonance at the pump frequency ω as well as at the signal frequency 2ω (depending on the dispersion of the metal).

This formalism corresponds to a new integral theory of diffraction in NLO valid both for TE and TM polarized SH signal. In this formalism, the groove depth δ is not considered as a perturbative parameter.

We show that there is a SP resonance induced enhancement, E, of the SH efficiency with respect to the flat case. Moreover, there exists an optimum value δ_{opt} of δ for which this enhancement is the greatest (E_{opt}).

In accordance with the theory, the experimental data show that there exists an optimum value of δ for which E is the greatest. Moreover, E_{opt} strongly depends on d since an increase of d from 0.556 μm to 1.53 μm leads to a strong increase of measured E_{opt} from 36 to 2500. It is also seen that the sinusoidal grating is, by far, not the best suited one when considering SP enhanced SHG. Indeed, trapezoidal silver grating may lead to super enhanced SHG with computed E_{opt} = 105 000.

Finally the following is worth noting : the optimum grating modulation, δ_{opt}/d, is of the order of $5\ 10^{-2}$. This means that a very shallow modulation leads to a strong enhancement of the SH efficiency.

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THIRD ORDER NONLINEAR INTERACTIONS AT SURFACES AND IN THIN FILMS

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Abstract not available

INTRINSIC INSTABILITIES OF LASER-IRRADIATED SURFACES

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Ordered and disordered surface morphologies can be induced at a surface by a single, intense laser beam that is broad enough to act essentially as a plane wave. Such patterns, which involve a breaking of the symmetry of the initial configuration, result from intrinsic instabilities in the response of surfaces to intense, coherent radiation. These laser-induced morphologies have been extensively studied, both experimentally and theoretically, by a number of researchers in connection with photodeposition, photoetching, and laser annealing, melting, and vaporization. Structure formation has been observed at the surfaces of metals, semiconductors, and insulators, at wavelengths from the infrared to the ultraviolet, and in time domains from picosecond pulses to continuous wave. A full understanding requires a consistent description of the response of the surface in the presence of the scattered light from the developing structure. We review our theoretical and experimental work on this nonequilibrium, symmetry-breaking phenomenon.